

*what is claimed is:*

1. A method of preparing a porous low-k dielectric layer on a substrate, the method comprising:

5 (a) forming a precursor film on the substrate, the precursor film comprising a porogen and a structure former;

(b) removing the porogen from the precursor film to thereby create voids within the dielectric material and form the porous low-k dielectric layer; and

10 (c) exposing the dielectric material to ultraviolet radiation in a manner that increases the mechanical strength of the porous low-k dielectric layer.

2. The method of claim 1, wherein the substrate is a semiconductor wafer.

3. The method of claim 2, wherein the porous low-k dielectric layer is formed 15 on the semiconductor wafer using a single-wafer or batch process.

4. The method of claim 1, wherein the precursor film comprises a porogen and a silicon-containing structure former.

20 5. The method of claim 1, wherein the precursor film is formed by co-depositing the porogen with the structure former.

6. The method of claim 1, wherein the structure former is produced from at least 25 one of a silane, an alkylsilane, an alkoxy silane, siloxane, carbon-doped variation thereof, or combination thereof.

7. The method of claim 1, wherein the structure former is produced from diethoxymethylsilane (DEMS), octamethylcyclotetrasiloxane (OMCTS), tetramethylcyclotetrasiloxane (TMCTS), dimethyldimethoxysilane (DMDMOS), carbon-doped oxides or a combination thereof.

30 8. The method of claim 1, wherein the porogen comprises a polyfunctional cyclic non-aromatic compound.

9. The method of claim 8, wherein the polyfunctional cyclic non-aromatic compound is an alpha-terpiene (ATRP) compound.

5 10. The method of claim 9, wherein the porogen comprises a mesoporous structure formed from a block copolymer.

11. The method of claim 1, wherein the precursor film is formed by a chemical vapor deposition process, plasma-enhanced CVD (PECVD) or a spin-on technique.

10 12. The method of claim 1, wherein (b) involves exposing the porogen within the precursor film to ultraviolet radiation.

15 13. The method of claim 12, wherein the ultraviolet radiation comprises a wavelength at or near an absorption peak of the porogen.

14. The method of claim 12, wherein the ultraviolet radiation comprises a wavelength distribution ranging from about 156 nm to about 800 nm.

20 15. The method of claim 12, wherein exposure to ultraviolet radiation occurs for a time period ranging between about 1 second and about 60 minutes.

25 16. The method of claim 12, wherein the substrate temperature during ultraviolet radiation exposure ranges between about minus10 and about 600 degrees Celsius, preferably below 400 degrees Celsius.

17. The method of claim 1, wherein at least part of (b) and (c) occur simultaneously.

30 18. The method of claim 1, wherein (c) is performed under an ambient comprising at least one of argon, nitrogen, helium, hydrogen, oxygen, carbon dioxide, and a combination thereof.

19. The method of claim 1, wherein (c) is performed under vacuum.

35 20. The method of claim 1, wherein (c) involves using ultraviolet radiation comprising a wavelength distribution ranging from about 156 to about 800 nm.

21. The method of claim 1, wherein (c) involves using ultraviolet radiation with intensities ranging between about 1  $\mu\text{W}/\text{cm}^2$  and about 3000  $\text{mW}/\text{cm}^2$ .

5 22. The method of claim 1, wherein (c) occurs for a time period ranging between about 1 second and about 60 minutes.

10 23. The method of claim 1, wherein (c) involves using a substrate temperature ranging between about minus 10 and about 450 degrees Celsius.

15 24. The method of claim 1, wherein (c) is performed at pressures ranging between about 1  $\mu\text{Torr}$  and about 760 Torr (atmospheric pressure).

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15 25. The method of claim 1, wherein after (c), the porous low-k dielectric layer has a hardness value ranging between about 0.5 GPa and about 3 GPa.

20 26. The method of claim 1, wherein (a), (b) and (c) are repeated to form a film with desired properties.

25 27. The method of claim 1, further comprising providing a reactive gas that cleans porogen residue from an apparatus in which the porogen is removed from the precursor film.

25 28. The method of claim 27, wherein providing a reactive gas that cleans porogen residue from an apparatus comprises introducing a gas into the apparatus and exposing the gas to ultraviolet radiation having a wavelength that activates the gas.

30 29. The method of claim 28, wherein the gas is oxygen.

30 30. A method of preparing a porous low-k dielectric layer on a substrate, the method comprising:

35 (a) providing in a reaction chamber a substrate having a precursor film comprising a porogen and a structure former;

(b) exposing the porogen from the precursor film to ultraviolet radiation of a first wavelength distribution to thereby create voids within the dielectric material and form the porous low-k dielectric layer;

5 (c) exposing the dielectric material to ultraviolet radiation of a second wavelength distribution to increase the mechanical strength of the porous low-k dielectric layer; and

10 (d) activating a gas by exposure to ultraviolet radiation of a third wavelength distribution to produce a species that cleans porogen residue from surfaces within the reaction chamber.

15 31. The method of claim 30, wherein the ultraviolet radiation of a first wavelength distribution includes radiation at a wavelength at or near an absorption peak of the porogen.

20 32. **R. 1.36** The method of claim 30, wherein the ultraviolet radiation of a second wavelength distribution includes radiation with a wavelengths ranging from about 156 to about 800 nm.

25 33. The method of claim 30, wherein first, second and third wavelength distributions are produced by first, second, and third ultraviolet sources, respectively.

34. The method of claim 30, wherein the gas in (d) oxygen.

35. The method of claim 30, wherein activating the oxygen in (d) produces at least one of ozone and active oxygen radicals.

36. The method of claim 30, wherein the ultraviolet radiation of a third wavelength distribution includes radiation with a wavelengths ranging from about 150 to about 250 nm.

37. The method of claim 30, wherein the ultraviolet radiation of a third wavelength distribution includes radiation with an intensity ranging between about 1  $\mu\text{W}/\text{cm}^2$  and about 3000  $\text{mW}/\text{cm}^2$ .

38. The method of claim 30, wherein (d) occurs for a time period ranging between about 1 second and about 60 minutes.

39. The method of claim 30, wherein the gas in (d) comprises at least one of a fluorine-containing gas or an oxygen-containing gas.

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39. The method of claim 30, further comprising evacuating the reaction chamber to remove volatilized porogen residue during (d).

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40. An apparatus for producing a low-k dielectric layer on a partially fabricated integrated circuit, the apparatus comprising:

(a) a support for holding the partially fabricated integrated circuit; and

(b) a plurality of ultraviolet sources positioned to direct ultraviolet radiation onto the partially fabricated integrated circuit, wherein individual ones of the plurality of ultraviolet sources provide different wavelength distributions of ultraviolet radiation, with each distribution being separately chosen for one or more of the following operations: (i) removing porogen from a dielectric layer precursor, (ii) reconstructing chemical bonds in the dielectric layer to improve mechanical strength, and (iii) cleaning porogen residue from the apparatus.

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41. The apparatus of claim 40, wherein the plurality of ultraviolet sources comprises at least two sources.

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42. The apparatus of claim 40, further comprising a control system for illuminating a first set of one or more of the ultraviolet sources during at least a porogen removal phase,

illuminating a second set of one or more of the ultraviolet sources during at least a chemical bond reconstruction phase, and

illuminating a third set of one or more of the ultraviolet sources during at least a cleaning phase.

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43. The apparatus of claim 42, wherein at least one of the ultraviolet sources of first set is/are also in the second set of the ultraviolet sources.

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44. The apparatus of claim 42, wherein at least one of the ultraviolet sources of first set is/are also in the third set of the ultraviolet sources.

*46*

45. The apparatus of claim 42, wherein at least one of the ultraviolet sources of second set is/are also in the third set of the ultraviolet sources.

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46. The apparatus of claim 40, further comprising a source of cleaning gas that will be activated by ultraviolet radiation to produce species that clean porogen residue from the apparatus.

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5 47. The apparatus of claim 46, wherein the cleaning gas is oxygen.

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48. The apparatus of claim 40, wherein the ultraviolet sources are maintained in fixed position with respect to the support during operation.

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10 49. The apparatus of claim 40, wherein the ultraviolet sources are movable with respect to the support during operation.

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15 50. The apparatus of claim 40, wherein the plurality of ultraviolet sources comprises at least two sources having substantially the same wavelength distribution of ultraviolet radiation.

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51. The apparatus of claim 40, wherein at least one of the ultraviolet sources is a lamp producing a relatively broad wavelength distribution of ultraviolet radiation.

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20 52. The apparatus of claim 40, wherein at least one of the ultraviolet sources is a laser producing a relatively narrow wavelength distribution of ultraviolet radiation.

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25 53. The apparatus of claim 40, wherein the plurality of ultraviolet sources comprises one or more of a mercury lamp, a deuterium lamp, a xenon lamp, and an excimer laser.